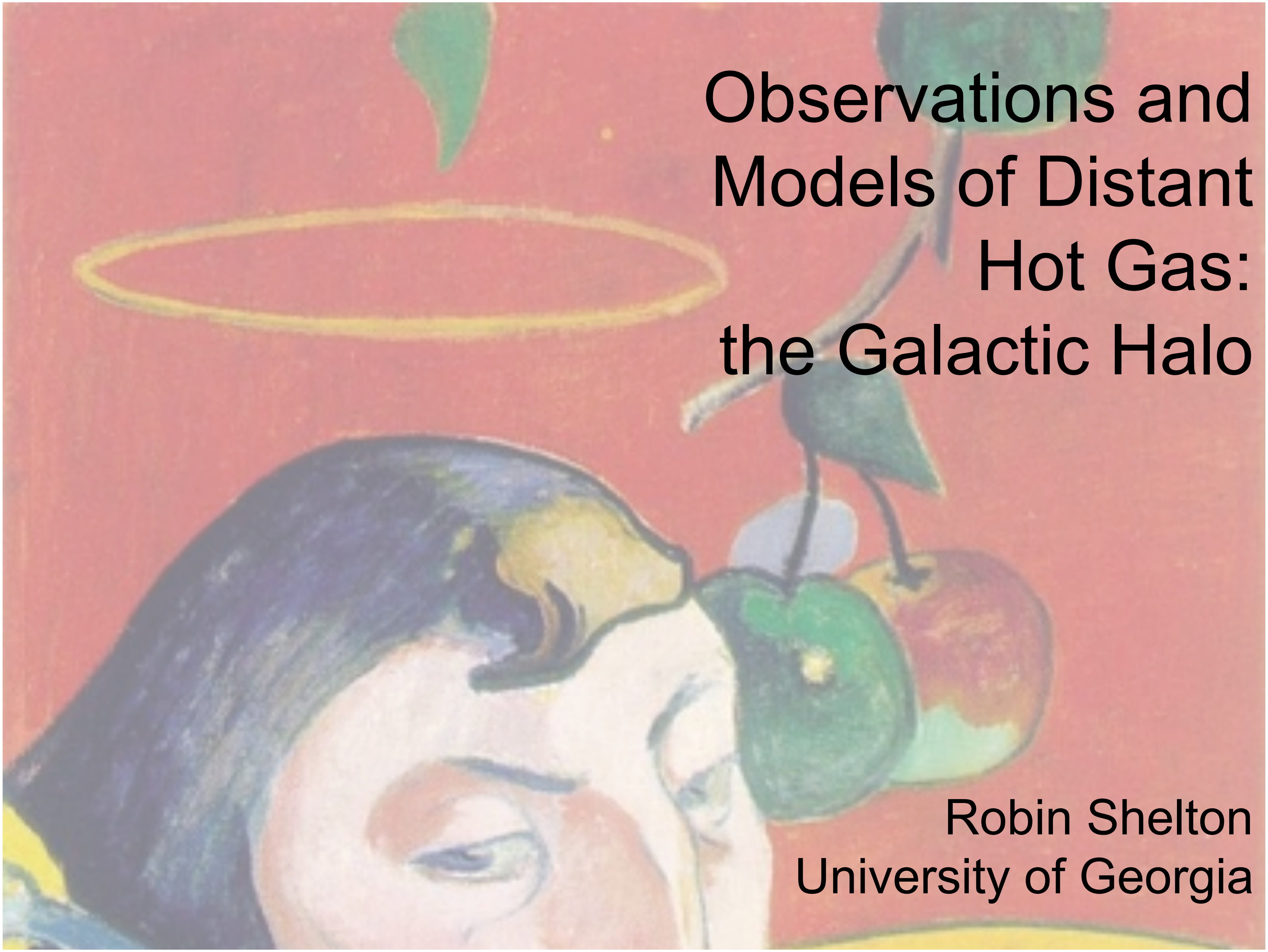

Observations and Models of Distant Hot Gas: the Galactic Halo

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Outline

- Relationship with the Local Bubble
- Characteristics of the hot gas in the halo
- Why is this gas hot?
- What is new and where are we going?

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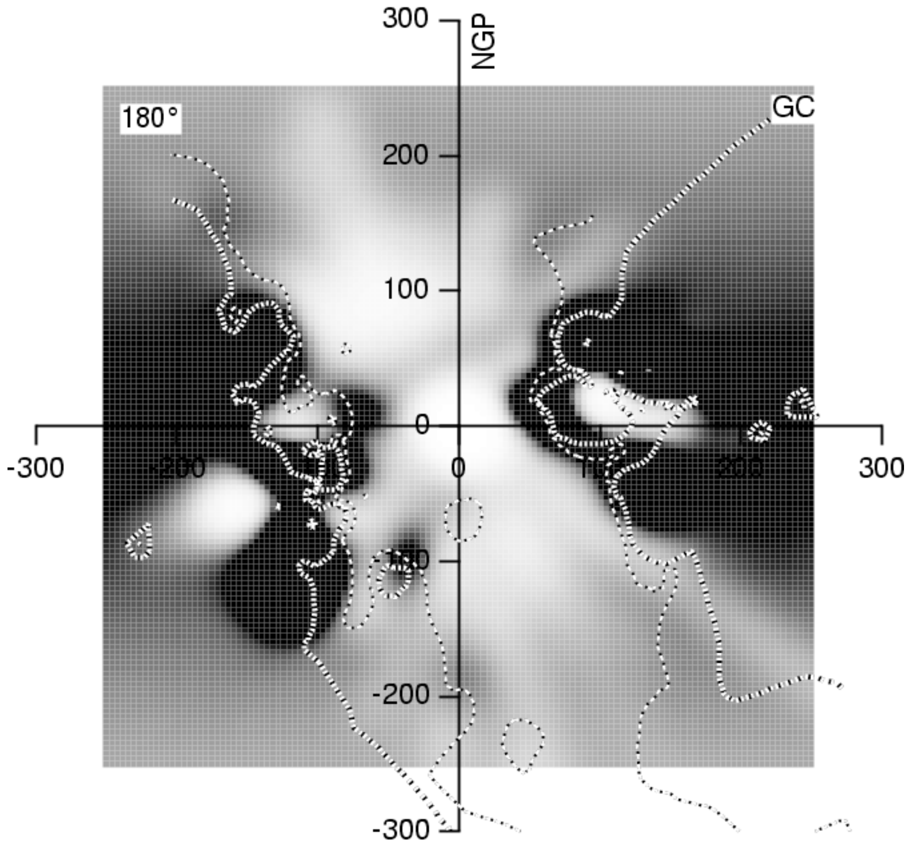
Relationship between LB and halo

- Some suggest that LB connects to the halo
- Some suggest that large bubbles vent into and heat the halo
- Halo provides pressure to LB
- Both LB and halo contain gas heated by energetic events

Local Cavity



Lallement et al. 2003

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Characteristics of halo gas

- All temperatures are represented

- Hot component:
  $T = 3 \times 10^5$ to $\sim 3 \times 10^6$ K studied through
  O VI absorption, O VI emission,
  1/4 keV emission, 3/4 keV emission
  select X-ray absorption lines (e.g. O VII)

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Height above Galactic Plane

- O VI column density:

  $n_{OVI}(z) = n_{OVI}(0)e^{-|z|/h}$

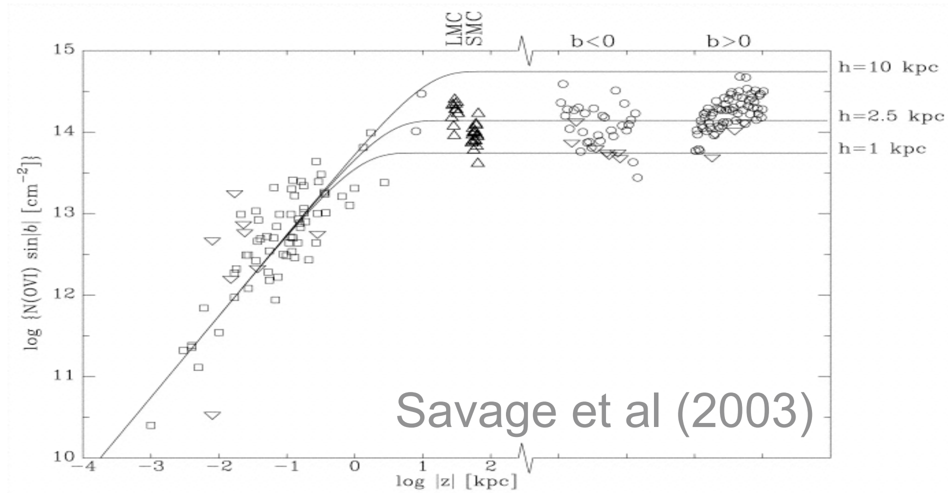
  Scale height ~2.3 kpc

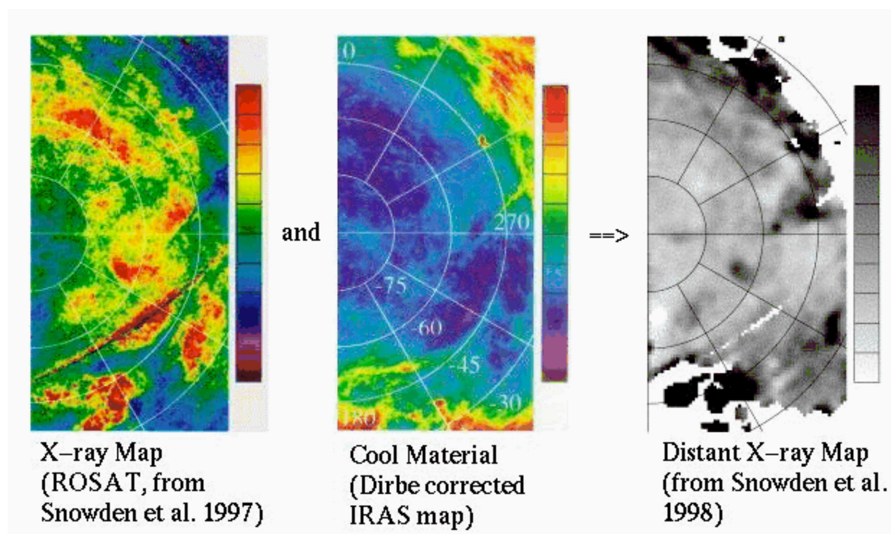
  (Savage et al. 2003)
- O VI emission scale height = unknown
- Soft X-rays:

  Shadowing shows X-rays above the gal. HI layer, some above 1.5 kpc (Herbstmeier et al. 1995)
- O VI, O VII & O VIII emission and absorption:

  $T = (10^{6.44}\ K)\ e^{-|z|/1kpc}$

  (Yao & Wang 2007)





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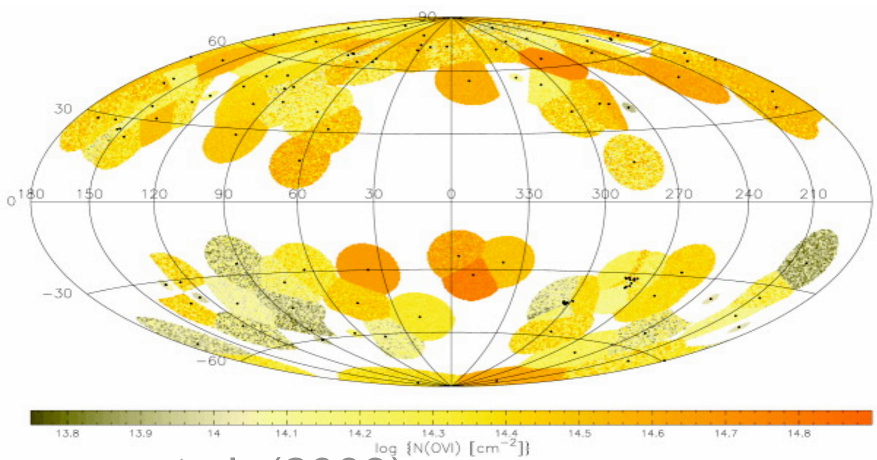
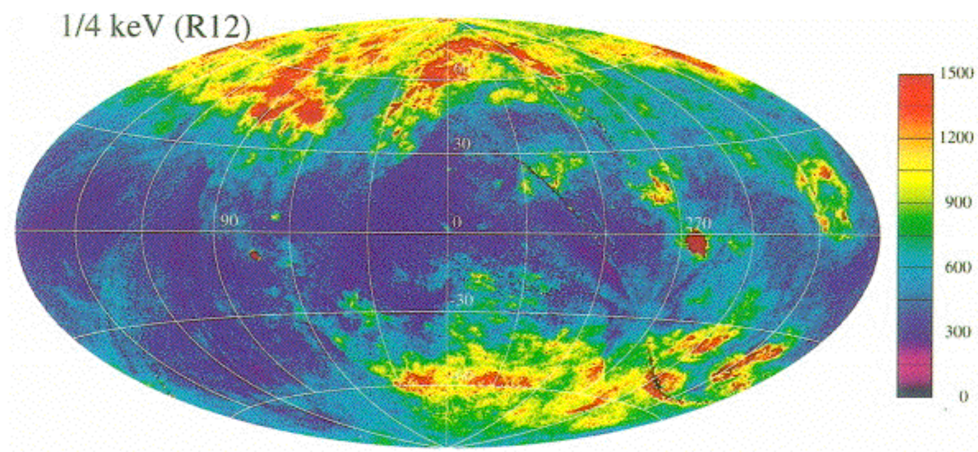
Hot Gas "Covers" the Northern and Southern Skies



Savage et al. (2003)



Snowden et al. (1997)

- There are O VI ions on every long high-latitude sight line
- 1/4 keV X-ray emission originates across most of the high latitude sky
- The northern sky is richer than the southern sky
- Sky coverage does not equate to filling factor
  - The filling factor of O VI-rich gas is a few percent

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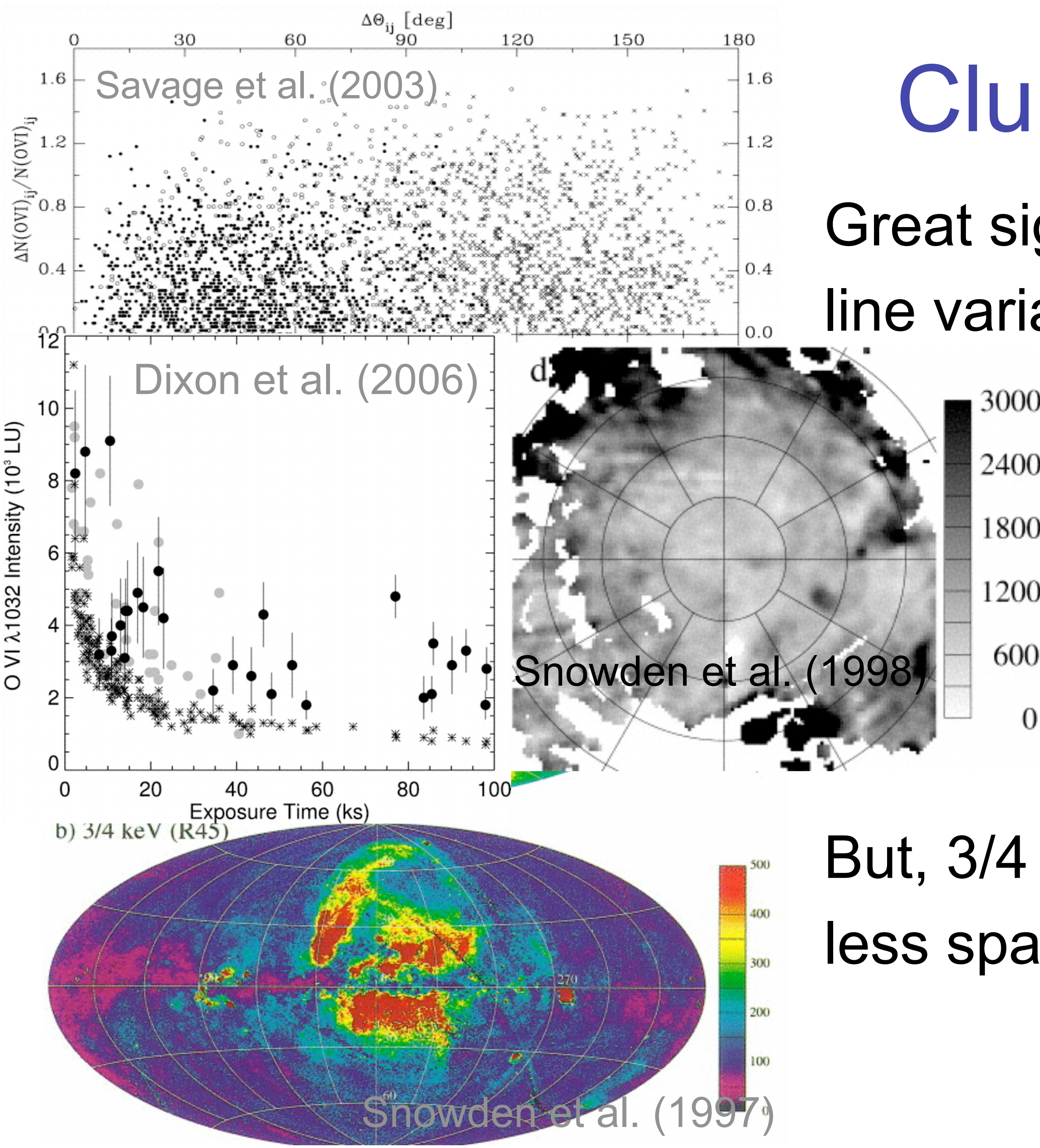

Clumpiness

Great sight-line to sight line variation in:

O VI column density

O VI emission

1/4 keV maps

But, 3/4 keV map displays less spatial variation

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Temperature

- There are a range of temperatures rather than a couple of single temperature components
- Compare halo O VI emission and and X-ray data for same direction(s)

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Multiwavelength Shadowing Observations

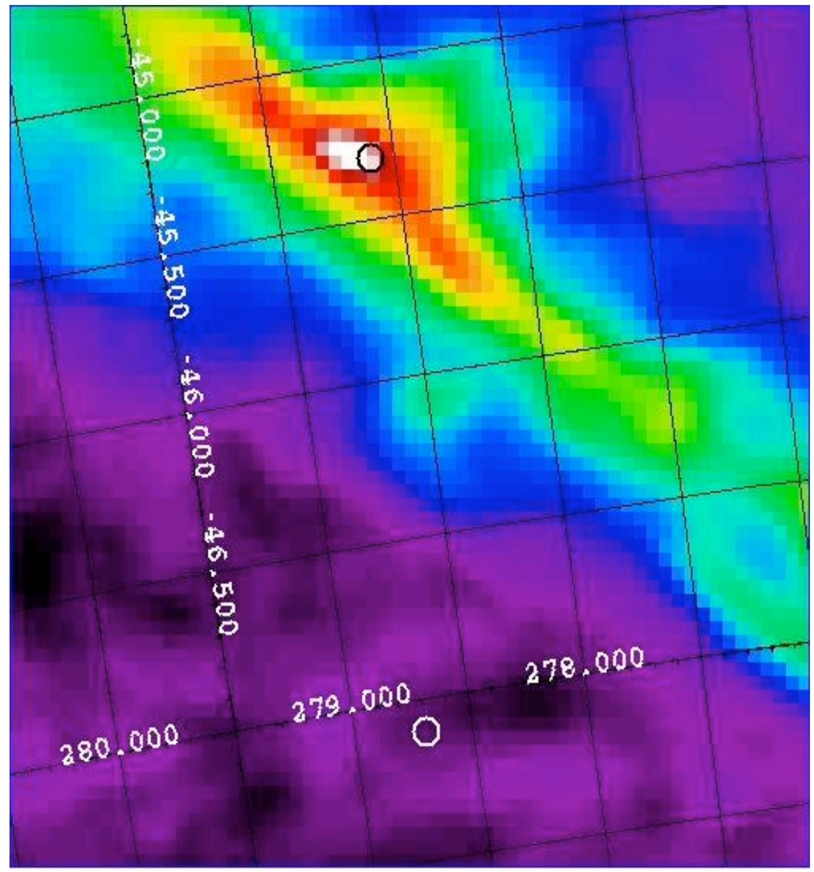
- Local O VI component:

  $I_{OVI(1\sigma)}$ = 30 (+340,-30) ph/s/cm^2/sr (Shelton, 2003)
- Halo O VI component:

  I_{halo} = 5350 (+650,-750) (Shelton, Sallmen & Jenkins, 2007)
- Local 1/4 keV component:

  534 ± 131 counts s^{-1} arcmin^{-2} (RASS)
- Halo 1/4 keV component:

  779 ± 151 counds s^{-1} arcmin^{-2} (RASS)
- Halo radiates 5 times more energy through the O VI doublet than through the entire 1/4 keV band (Shelton, Sallmen & Jenkins, 2007) and 10 times more than O VII (Henley & Shelton, 2008)



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Physical Parameters of the O VI-rich Gas in the Halo

- $\langle n_e \rangle = (4\pi\ I_{doublet}) / (\langle \sigma \upsilon \rangle\ N_{OVI})$
- $\Delta l = N_{OVI} / n_{OVI} = N_{OVI} / [n_e\ (H/e)\ (O/H)_{\odot}\ f_{OVI}(T_{max})]$

- Take N_{OVI} from average of nearby sight lines (Savage et al. 2003), subtract Local Bubble (data from Savage & Lehner, 2006):

  $N_{OVI} = 2.09 \pm 0.84 \times 10^{14}$ cm^{-2} for halo

- If $N_H = 0.5 \times 10^{20}$ cm^{-2}, then

  $n_e = 0.011 \pm 0.005$ cm^{-3},

  $P_{th}/k = 6700(+2800,-2900)$ K cm^{-3}

  $\Delta l = 70 \pm 57$ pc

  Tcool < 7.4 ± 3.1 Myr

- If $N_H = 2 \times 10^{20}$ cm^{-2}, then

  $n_e = 0.016 \pm 0.007$ cm^{-3},

  $P_{th}/k = 10{,}000(+4200,-4300)$

  $\Delta l = 47 \pm 38$ pc

  Tcool < 4.9 ± 2.1 Myr

overhead credit: R. Shelton

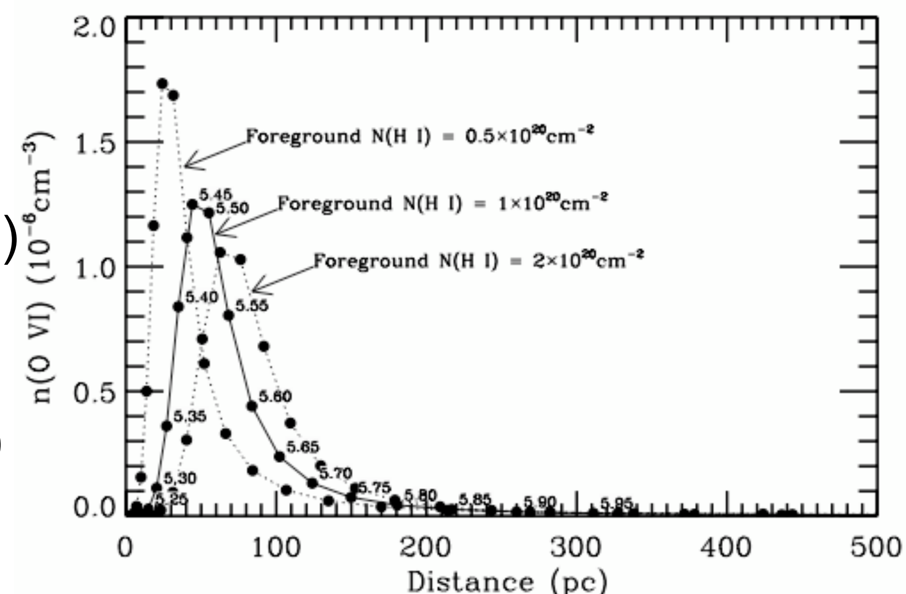
Volume Distribution Function of Temperature

Assume the volume occupation of hot gas follows power law form:

Constrain with I_{OVI}, N_{OVI}, ROSAT 1/4 keV (absorbed halo = $732 \pm 142 \times 10^{-6}$ counts s^{-1} arcmin^{-2}) and assumption of pressure balance

$d\mathcal{L}I \propto T^{(1.5 \pm 0.6)}\, d\mathcal{L}(\ln T)$

- For $N_H = 0.5 \times 10^{20}$ cm^{-2} case:
  $d\mathcal{L}I = 10^{(-4.25 \pm 0.37)}\, T^{(1.15 \pm 0.20)}\, d\mathcal{L}(\ln T)$
  units = $K^{-\beta}$ pc
- For $N_H = 2 \times 10^{20}$ cm^{-2} case:
  $d\mathcal{L}I = 10^{(-8.92 \pm 0.37)}\, T^{(1.95 \pm 0.17)}\, d\mathcal{L}(\ln T)$



Shelton, Sallmen & Jenkins (2007)

overhead credit: R. Shelton

Temperature Distribution Function
⇒ Large Radiative Cooling Rate

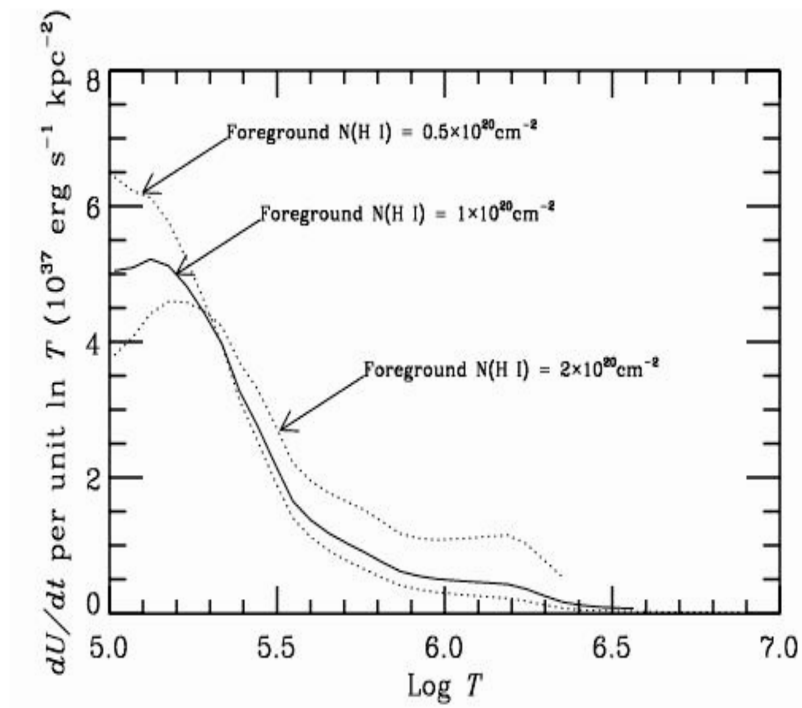
Radiative cooling rate by hot gas
(10^5 K < T < $10^{6.5}$ K, both sides of Galactic plane):

~6×10^{38} ergs/s/kpc^2

For $N_H = 0.5 \times 10^{20}$ cm^{-2},
rate = 4.7 to 6.2×10^{38} ergs/s/kpc^2
For $N_H = 2 \times 10^{20}$ cm^{-2},
rate = 5.2 to 6.9×10^{38} ergs/s/kpc^2

Hot halo gas radiates most of energy injected by SN + pre-SN winds:

(SN + pre-SN wind energy input = 7.7 to 8.1×10^{38} ergs/s/kpc^2)



Shelton, Sallmen & Jenkins (2007)

overhead credit: R. Shelton

Distribution Functions also work at Higher T

- Yao & Wang (2007):

  jointly fit O VI (abs), O VII, O VIII (abs and emiss) measurements to a temperature power law

- Lei et al. (2008):

  fit the Suzaku + ROSAT data for the filament shadow to a temperature power law, but did find a break between the O VI - 1/4keV section and the 1/4 keV - 3/4 keV section

overhead credit: R. Shelton

Why is hot gas in the halo?

Potential Sources:

- Galactic Sources
  - Fountains
  - “halo” SNRs
- Extragalactic Sources
  - Accretion from IGM
  - Infalling clouds

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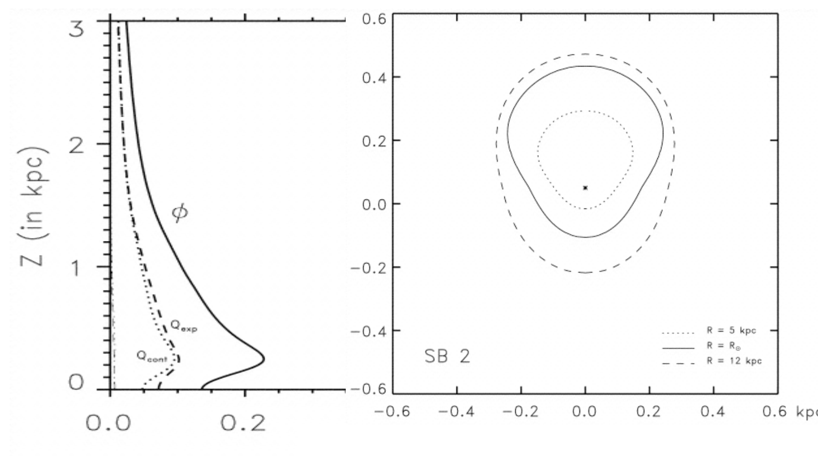
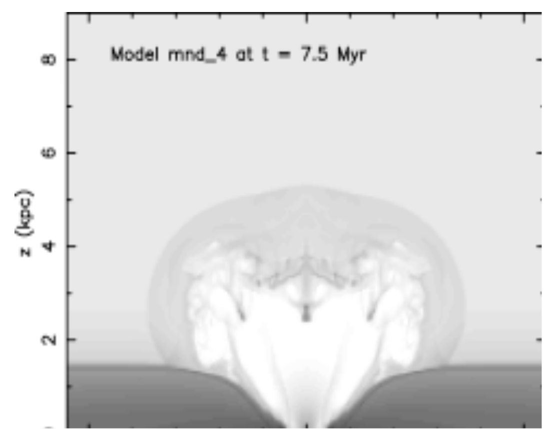
Superbubbles, Fountains

- Ferriere (1998) superbubble simulations put little hot gas in halo



- Strickland & Stevens (2000) starburst (1000 × stronger than Arches) puts material at greater height, but such star clusters aren't expected in the Milky Way



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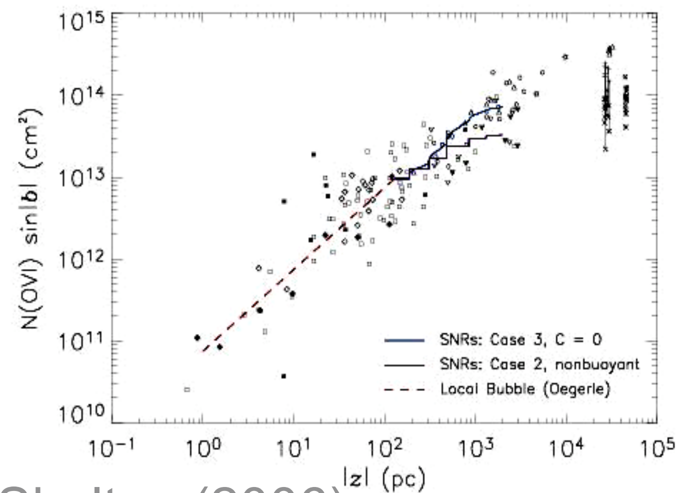
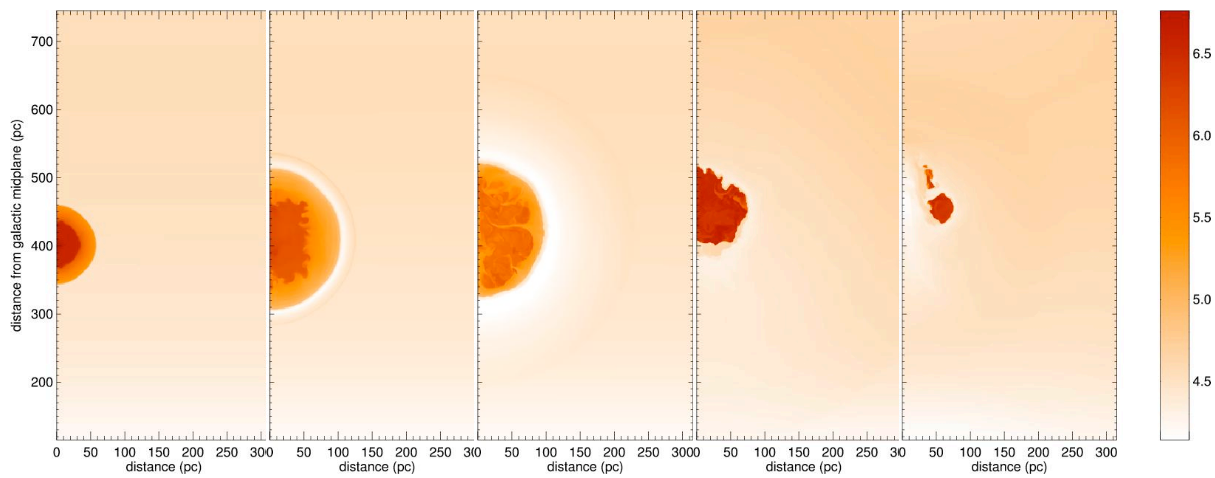
Isolated SNRs



Shelton (2006)



Raley et al. (2007)

- The scale height for isolated SN is ~300 pc
- They put some hot gas into the thick disk, but not beyond ~2 kpc
- Not significantly buoyant

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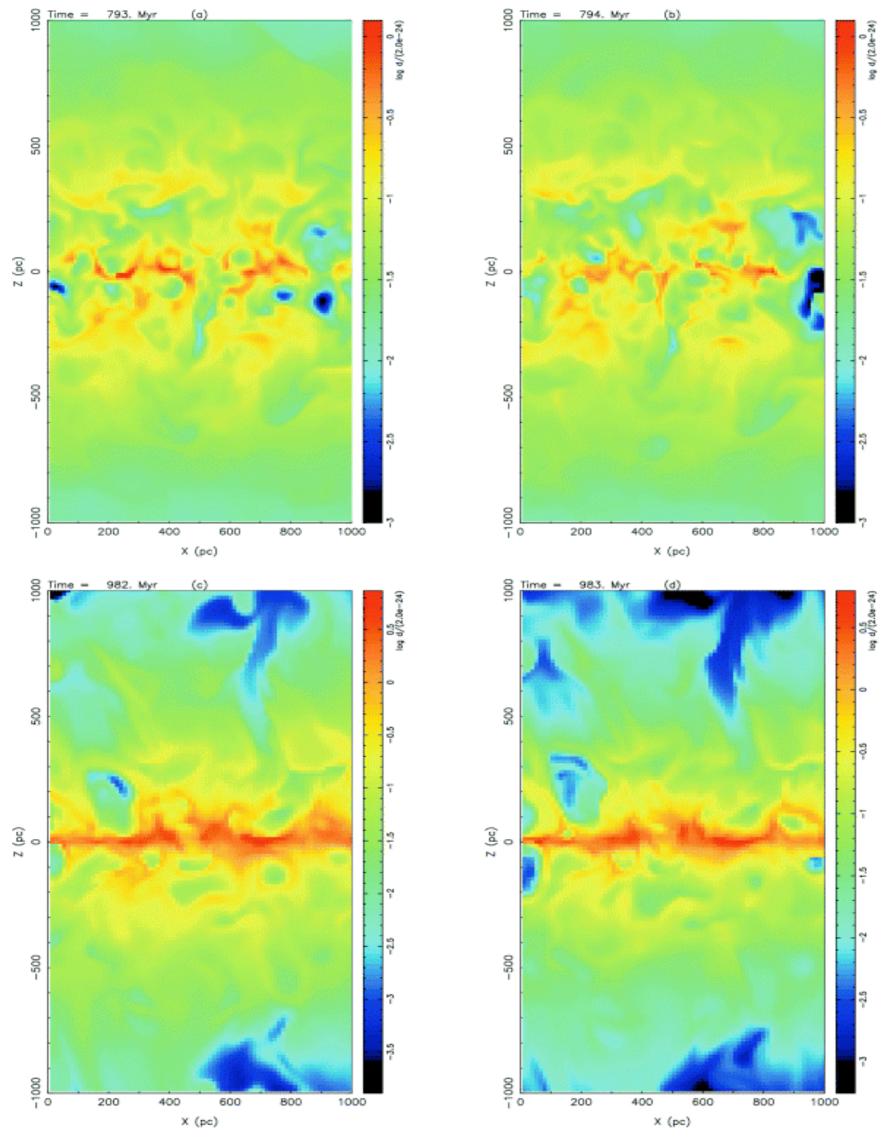
The Disk Matters

- Strickland & Stevens (2000) found fluffiness of disk to be more important than the SN rate
- de Avillez & Breitschwerdt (2004) found that the disk dynamically evolves such that it allows hot gas to flow upwards



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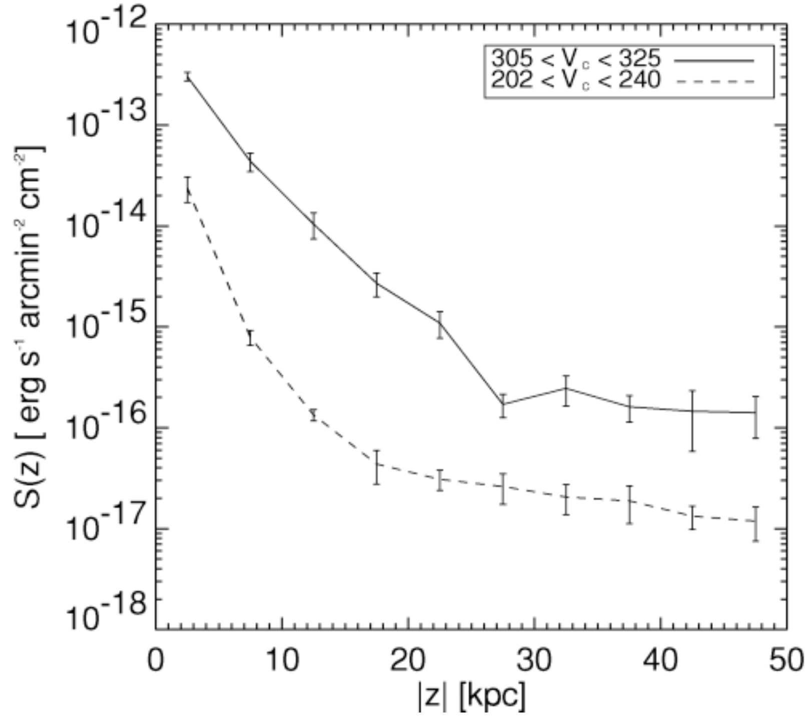
External Sources

- Accretion of IGM can result in hot gas; Toft et al. (2002) predict large X-ray scale height
- Kerp et al. (1996) suggest high velocity cloud impacts contribute X-ray emission



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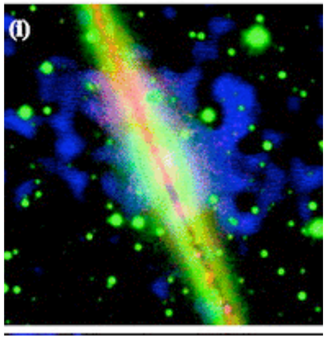
Halo: What's New, Where Might We Be Going?

- Parameterizing spectrum as power law rather than individual thermal components
- Suggestions that Galactic halo has a hot component 40 kpc from disk (because O VI is seen on Magellanic Stream)

overhead credit: R. Shelton

Conclusions

- There is $T = 3 \times 10^5$ to 3×10^6 K gas above the plane
- Covers much of the sky, but is patchy
- Excellent radiator for the Galaxy
- Sources are still being studied ----- the hot gas in the thick disk is easier to explain than the higher hot gas



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Tidbits:

- The title image is part of Paul Gauguin’s self portrait, painted in 1889.